Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

Thursday 14 November 2019 (morning)

1 hour 15 minutes

Candidate session number

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[45 marks]**.

Section A	Questions
Answer all questions.	1 – 2

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Materials	3 – 9
Option B — Biochemistry	10 – 15
Option C — Energy	16 – 20
Option D — Medicinal chemistry	21 – 27

8819–6103

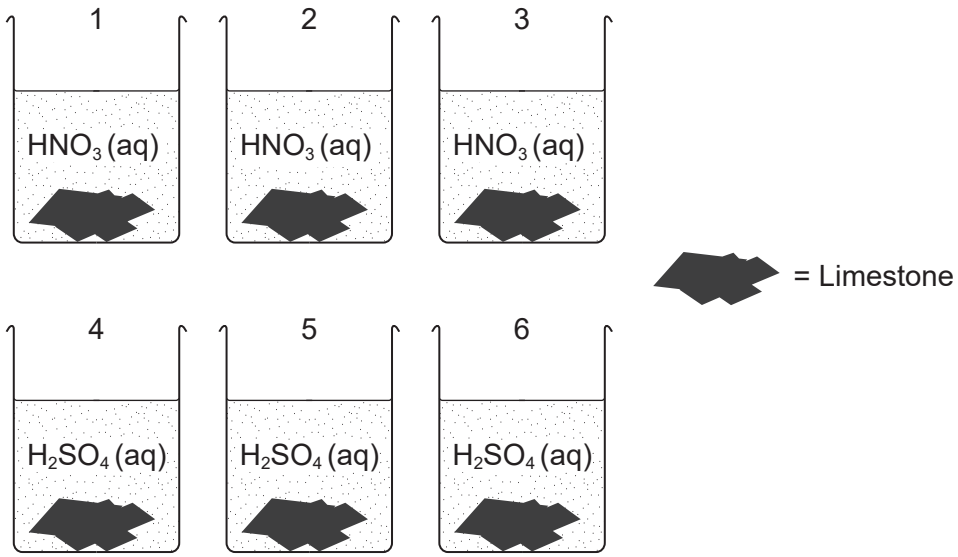
Section A

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A student investigated how the type of acid in acid deposition affects limestone, a building material mainly composed of calcium carbonate.

	Solubility
calcium carbonate	insoluble
calcium nitrate	soluble
calcium sulfate	slightly soluble

The student monitored the mass of six similarly sized pieces of limestone. Three were placed in beakers containing 200.0 cm^3 of 0.100 mol dm^{-3} nitric acid, HNO_3 (aq), and the other three in 200.0 cm^3 of 0.100 mol dm^{-3} sulfuric acid, H_2SO_4 (aq).



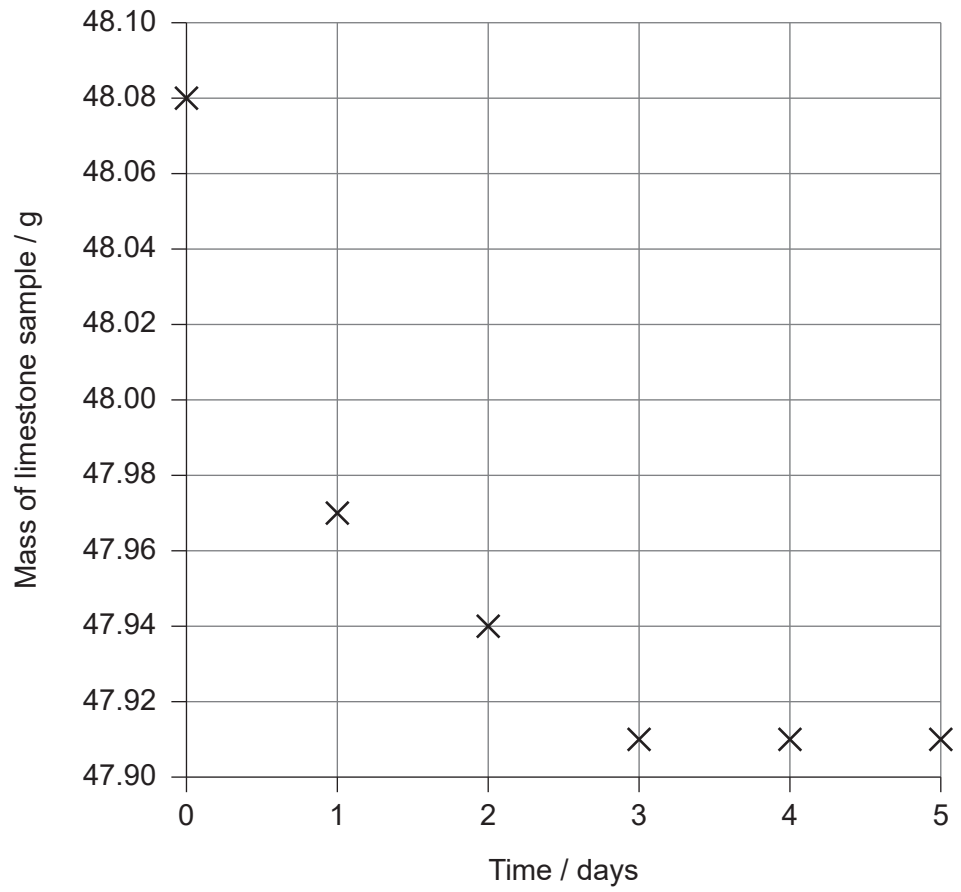
[Source: © International Baccalaureate Organization 2019]

(This question continues on the following page)

(Question 1 continued)

The limestone was removed from the acid, washed, dried with a paper towel and weighed every day at the same time and then replaced in the beakers.

The student plotted the mass of one of the pieces of limestone placed in nitric acid against time.



[Source: © International Baccalaureate Organization 2019]

(a) Draw a best-fit line on the graph. [1]

(b) (i) Determine the initial rate of reaction of limestone with nitric acid from the graph. Show your working on the graph and include the units of the initial rate. [3]

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(This question continues on page 5)

Please **do not** write on this page.

Answers written on this page
will not be marked.

(Question 1 continued)

(ii) Explain why the rate of reaction of limestone with nitric acid decreases and reaches zero over the period of five days. [2]

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(iii) Suggest a source of error in the procedure, assuming no human errors occurred and the balance was accurate. [1]

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(c) The student hypothesized that sulfuric acid would cause a larger mass loss than nitric acid.

(i) Justify this hypothesis. [1]

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(ii) The student obtained the following total mass losses.

Acid	**Nitric acid**			**Sulfuric acid**		
Limestone sample	1	2	3	4	5	6
Total mass loss / g	0.17	0.14	0.15	0.10	0.07	0.08

She concluded that nitric acid caused more mass loss than sulfuric acid, which did not support her hypothesis.

Suggest an explanation for the data, assuming that no errors were made by the student. [1]

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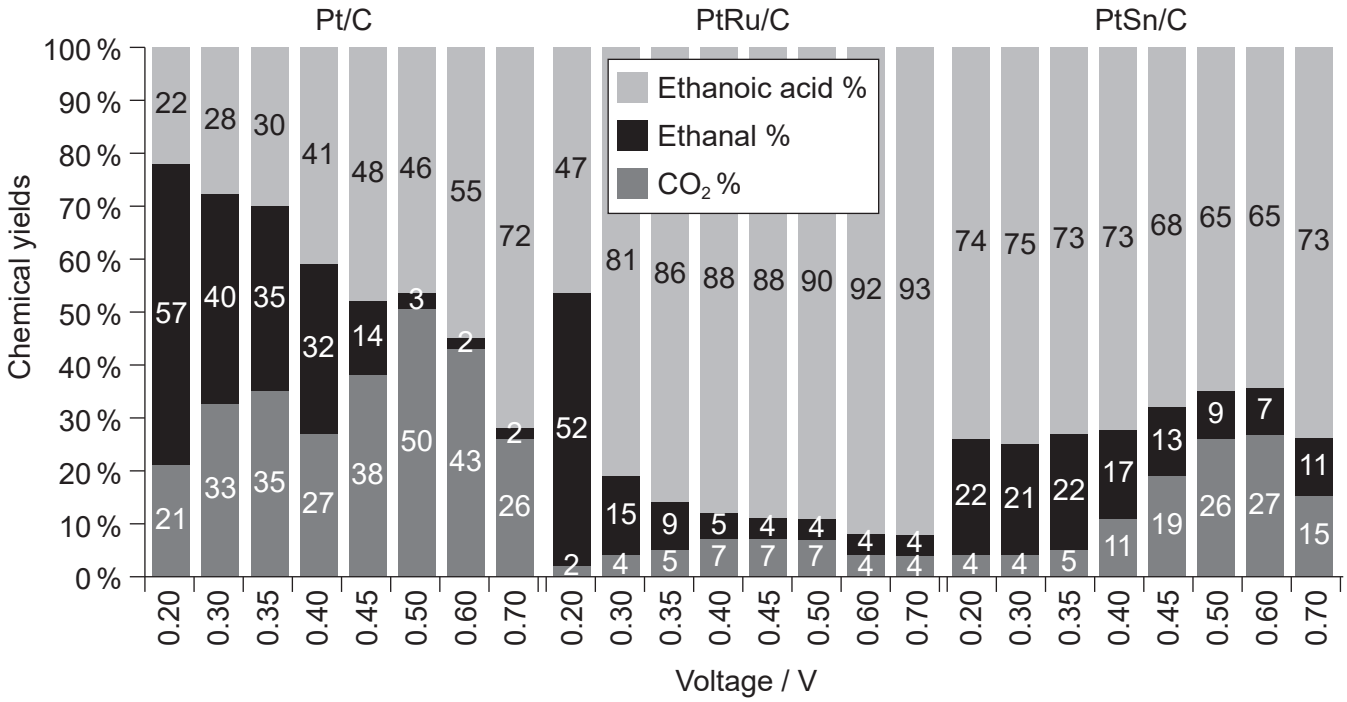
2. Ethanol was electrolysed at different voltages. The products at the anode, ethanoic acid, ethanal and carbon dioxide, were collected and analysed.

The percentages of products obtained using three different catalysts mounted on a carbon anode, platinum (Pt/C), platinum and ruthenium alloy (PtRu/C) and platinum and tin alloy (PtSn/C) are shown.



Chemical yields of ethanoic acid, ethanal and carbon dioxide as a function of voltage for oxidation of 0.100 mol dm^{-3} ethanol at Pt/C, PtRu/C and PtSn/C anodes at 80 °C.

[Source: Product Distributions and Efficiencies for Ethanol Oxidation in a Proton Exchange Membrane Electrolysis Cell, Rakan M. Altarawneh and Peter G. Pickup, *Journal of the Electrochemical Society*, 2017, volume **164**, issue 7, http://jes.ecsdl.org/. Distributed under the terms of the Creative Commons Attribution 4.0 License (CC BY, http://creativecommons.org/licenses/by/4.0/)]

(a) (i) Describe the effect of increasing the voltage on the chemical yield of: [2]

Ethanal using Pt/C:

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Carbon dioxide using PtRu/C:

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(This question continues on the following page)

(Question 2 continued)

(ii) Determine the change in the average oxidation state of carbon. [2]

From ethanol to ethanal:

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From ethanol to carbon dioxide:

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(iii) List the three products at the anode from the least to the most oxidized. [1]

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(b) Deduce, giving your reason, which catalyst is most effective at fully oxidizing ethanol. [1]

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Section B

Answer **all** of the questions from **one** of the options. Answers must be written within the answer boxes provided.

Option A — Materials

3. Catalysts are commonly used in industry.

(a) Describe how a heterogeneous catalyst provides an alternative pathway for a reaction. [2]

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(b) Nanotubes are used to support the active material in nanocatalysts.

Explain why oxygen cannot be used for the chemical vapour deposition (CVD) preparation of carbon nanotubes. [2]

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4. Superconductors have no resistance below a critical temperature.

(a) (i) Outline how resistance to electric currents occurs in metals. [1]

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(Option A continues on the following page)

(Option A, question 4 continued)

(ii) Suggest why the resistance of metals increases with temperature. [2]

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(b) State **two** differences between Type I and Type II superconductors. [2]

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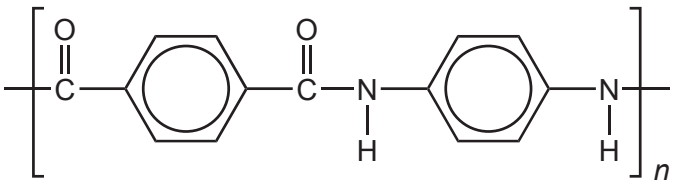
5. Kevlar® is used to make racing tires.



(a) Draw the structure of the monomers of Kevlar® if the by-product of the condensation polymerization is hydrogen chloride. [2]

(Option A continues on the following page)

(Option A, question 5 continued)

(b) State and explain why plasticizers are added to polymers. [2]

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(c) Discuss why the recycling of plastics is an energy intensive process. [2]

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6. Metals are extracted from their ores by various means.

(a) Discuss why different methods of reduction are needed to extract metals. [2]

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(Option A continues on the following page)

(Option A, question 6 continued)

(b) Aluminium is produced by the electrolysis of alumina (aluminium oxide) dissolved in cryolite.

(i) Determine the percentage of ionic bonding in alumina using sections 8 and 29 of the data booklet. [2]

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(ii) Write half-equations for the electrolysis of molten alumina using graphite electrodes, deducing the state symbols of the products. [3]

	Melting point / K
Alumina	2345
Cryolite	1285
Aluminium	933
Graphite	3500

Anode (positive electrode):

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Cathode (negative electrode):

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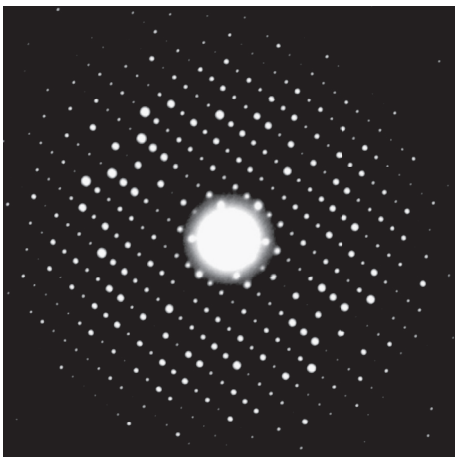
(Option A continues on the following page)

(Option A continued)

7. X-ray crystallography of a metal crystal produces a diffraction pattern of bright spots.



[Source: https://commons.wikimedia.org/wiki/File:Tant-ED.jpg]

Using X-rays of wavelength 1.54×10^{-10} m, the first bright spots were produced at an angle θ of 22.3 ° from the centre.

Calculate the separation between planes of atoms in the lattice, in meters, using section 1 of the data booklet. [1]

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8. 1.40×10^{-3} g of NaOH (s) are dissolved in 250.0 cm^3 of 1.00×10^{-11} mol dm^{-3} $Pb(OH)_2$ (aq) solution.

Determine the change in lead ion concentration in the solution, using section 32 of the data booklet. [4]

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(Option A continues on the following page)

(Option A continued)

9. A soap solution can form a liquid-crystal state.

(a) Describe the arrangement of soap molecules in the nematic liquid crystal phase. [2]

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(b) State how liquid crystals are affected by an electric field. [1]

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End of Option A

Option B — Biochemistry

10. Aspartame is formed from the two amino acids aspartic acid (Asp) and phenylalanine (Phe).

(a) Draw the structure of the dipeptide Asp–Phe using section 33 of the data booklet. [2]

(b) Chromatography is used in the analysis of proteins in the food and pharmaceutical industry.

(i) Describe, using another method, how a mixture of four amino acids, alanine, arginine, glutamic acid and glycine, could be separated when placed in a buffer solution of pH 6.0. [3]

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(ii) Suggest why alanine and glycine separate slightly at pH 6.5. [1]

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(iii) Calculate the ratio of $[A^-]$: [HA] in a buffer of pH 6.0 given that pK_a for the acid is 4.83, using section 1 of the data booklet. [1]

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(Option B continues on the following page)

(Option B continued)

11. The Michaelis–Menten equation describes the kinetics of enzyme-catalysed reactions.

(a) Outline the significance of the Michaelis constant K_m. [1]

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(b) Compare the effects of competitive and non-competitive inhibitors. [3]

	Competitive inhibitor	**Non-competitive inhibitor**
Binding site on enzyme	. . . .	. . . .
V_{max}	. . . .	. . . .
K_m	. . . .	. . . .

(Option B continues on the following page)

(Option B continued)

12. Stearic acid ($M_r = 284.47$) and oleic acid ($M_r = 282.46$) have the same number of carbon atoms. The structures of both lipids are shown in section 34 of the data booklet.

(a) The iodine number is the number of grams of iodine which reacts with 100 g of fat. Calculate the iodine number of oleic acid. [1]

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(b) The chemical change in stored fats causes rancidity characterized by an unpleasant smell or taste.

Compare hydrolytic and oxidative rancidity. [2]

Rancidity	Site of reactivity in the molecule	Conditions that favour the reaction
hydrolytic	. . . . .	. . . . .
	. . . . .	. . . . .
oxidative	. . . . .	. . . . .
	. . . . .	. . . . .

(c) State **one** similarity and **one** difference in composition between phospholipids and triglycerides. [2]

Similarity:

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Difference:

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(Option B continues on the following page)

(Option B continued)

13. DNA, deoxyribonucleic acid, is made up of nucleotides.

(a) List **two** components of nucleotides. [1]

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(b) Explain how the double-helical structure of DNA is stabilized once formed. [2]

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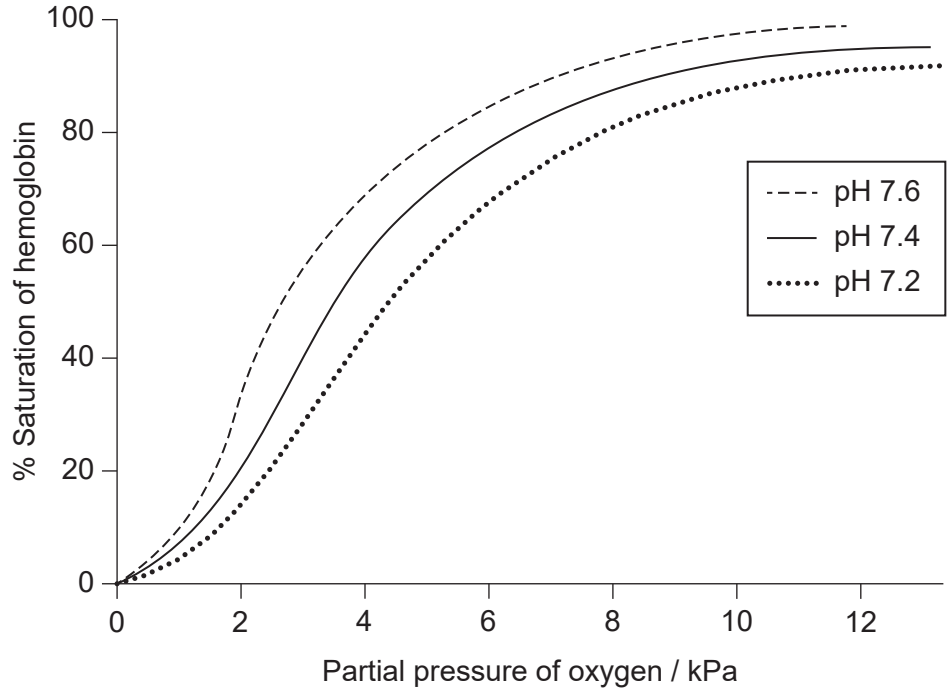
(Option B continues on the following page)

(Option B continued)

14. Changes in physiology can impact living creatures.

(a) The graph shows the change in oxygen partial pressure in blood, measured at different pH values.



[Source: © International Baccalaureate Organization 2019]

Explain the effect of changing pH on the percentage saturation of hemoglobin at a given partial pressure of oxygen. [2]

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(Option B continues on the following page)

(Option B, question 14 continued)

(b) Explain the biomagnification of the pesticide DDT. [2]

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(c) Vitamins are organic compounds essential in small amounts.

State the name of **one** functional group common to all three vitamins shown in section 35 of the data booklet. [1]

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15. (a) Describe the function of chlorophyll in photosynthesis. [2]

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(b) Compare and contrast the structures of starch and cellulose. [2]

One similarity:

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One difference:

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(Option B continues on the following page)

(Option B, question 15 continued)

(c) Explain why maltose, $C_{12}H_{22}O_{11}$, is soluble in water. [2]

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End of Option B

Option C — Energy

16. Consider the following data for butane and pentane at STP.

	Specific energy / MJ kg^{-1}	**Energy density / MJ m^{-3}**
Butane	49.5	128
Pentane	48.6	30400

(a) Discuss the data. [3]

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(b) Outline what is meant by the degradation of energy. [1]

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17. Octane number is a measure of the performance of engine fuel.

(a) Suggest why a high-octane number fuel is preferable. [1]

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(Option C continues on the following page)

(Option C, question 17 continued)

(b) (i) Reforming reactions are used to increase the octane number of a hydrocarbon fuel.

Suggest the structural formulas of **two** possible products of the reforming reaction of heptane, C_7H_{16}. [2]

(ii) The ^1H NMR spectrum of one of the products has four signals. The integration trace shows a ratio of the areas under the signals of 9 : 3 : 2 : 2.

Deduce the structural formula of the product. [1]

(Option C continues on the following page)

(Option C continued)

18. Red supergiant stars contain carbon-12 formed by the fusion of helium-4 nuclei with beryllium-8 nuclei.

Mass of a helium-4 nucleus = 4.002602 amu
Mass of a beryllium-8 nucleus = 8.005305 amu
Mass of a carbon-12 nucleus = 12.000000 amu

(a) (i) State the nuclear equation for the fusion reaction. [1]

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(ii) Explain why fusion is an exothermic process. [2]

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(iii) Calculate the heat energy released, in J, by the fusion reaction producing one atom of carbon-12. Use section 2 of the data booklet and $E = mc^2$. [3]

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(Option C continues on the following page)

(Option C, question 18 continued)

(b) Beryllium-8 is a radioactive isotope with a half-life of 6.70×10^{-17} s.

Calculate the mass of beryllium-8 remaining after 2.01×10^{-16} s from a sample initially containing 4.00 g of beryllium-8. [2]

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(Option C continues on the following page)

(Option C continued)

19. Ethanol is a biofuel that can be mixed with gasoline.

(a) Write the equation for the complete combustion of ethanol. [1]

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(b) Outline the evidence that relates global warming to increasing concentrations of greenhouse gases in the atmosphere. [2]

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(c) Explain, including a suitable equation, why biofuels are considered to be carbon neutral. [2]

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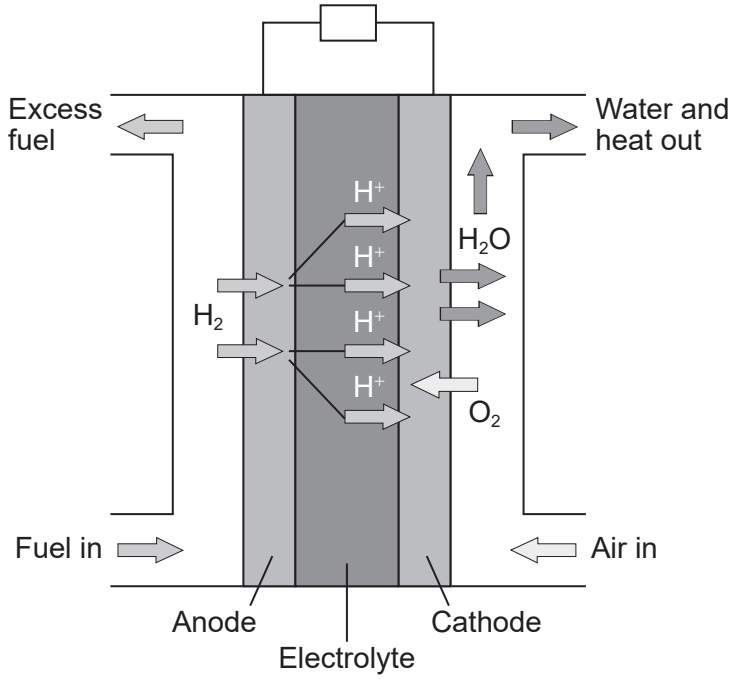
(Option C continues on the following page)

(Option C continued)

20. A proton-exchange membrane (PEM) fuel cell uses pure hydrogen gas as the fuel and a proton exchange membrane as the electrolyte.



[Source: https://en.wikipedia.org/wiki/File:Proton_Exchange_Fuel_Cell_Diagram.svg]

(a) Deduce the half-equations for the reactions occurring at the electrodes. [2]

Anode (negative electrode):

. . . . . .

. . . . . .

Cathode (positive electrode):

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(b) (i) Calculate the cell potential, $E^{\ominus}$, in V, using section 24 of the data booklet. [1]

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(Option C continues on the following page)

(Option C, question 20 continued)

(ii) Suggest how PEM fuel cells can be used to produce a larger voltage than that calculated in (b)(i). [1]

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(c) Suggest an advantage of the PEM fuel cell over the lead-acid battery for use in cars. [1]

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(d) A dye-sensitized solar cell (DSSC) uses light energy to produce electricity.

(i) Outline the functions of the dye, TiO_2 and the electrolyte in the operation of the DSSC. [3]

Dye:

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TiO_2:

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Electrolyte:

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(Option C continues on the following page)

(Option C, question 20 continued)

(ii) Suggest an advantage of the DSSC over silicon-based photovoltaic cells. [1]

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End of Option C

Option D — Medicinal chemistry

21. Codeine, morphine and diamorphine (heroin) are derived from opium.

(a) Explain why diamorphine has greater potency than morphine. [3]

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(b) Experimental research on both animals and humans contributes to the development of pharmaceuticals.

State the meaning of the term therapeutic index in human studies. [1]

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22. Body fluids have different pH values.

(a) Identify the compound responsible for the acidity of gastric juice, and state whether it is a strong or weak acid. [1]

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(b) Outline how ranitidine reduces stomach acidity. [1]

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(Option D continues on the following page)

(Option D, question 22 continued)

(c) Calculate the pH of a buffer solution which contains $0.20\,mol\,dm^{-3}$ ethanoic acid and $0.50\,mol\,dm^{-3}$ sodium ethanoate. Use section 1 of the data booklet.

pK_a (ethanoic acid) = 4.76 [1]

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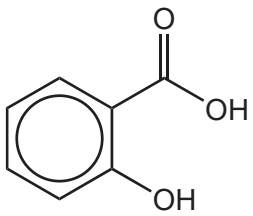
23. The structure of aspirin is shown in section 37 of the data booklet.



Salicylic acid

(a) Suggest **one** reactant used to prepare aspirin from salicylic acid. [1]

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(b) Aspirin, $C_6H_4(OCOCH_3)COOH$, is only slightly soluble in water.

Outline, including an equation, how aspirin can be made more water-soluble. Use section 37 in the data booklet. [2]

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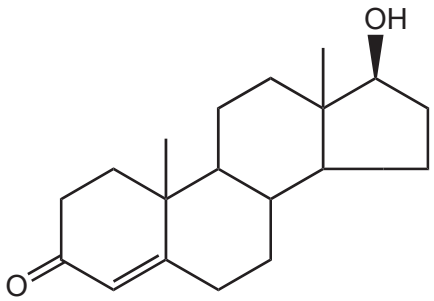
(Option D continues on the following page)

(Option D continued)

24. Steroids are lipids with a steroidal backbone. The structure of cholesterol is shown in section 34 of the data booklet.

(a) Infrared (IR) spectroscopy is used to identify functional groups in organic compounds.



Testosterone

Deduce the wavenumber, in cm^{-1}, of an absorption peak found in the IR spectrum of testosterone but not in that of cholesterol. [1]

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(b) Describe a technique for the detection of steroids in blood and urine. [3]

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(c) Explain how redox chemistry is used to measure the ethanol concentration in a breathalyser. [2]

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(Option D continues on the following page)

(Option D continued)

25. The discovery of penicillins contributed to the development of antibiotics.

(a) Explain how the beta-lactam ring is responsible for the antibiotic properties of penicillin. Refer to section 37 of the data booklet. [3]

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(b) Outline the impact of antibiotic waste on the environment. [1]

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(c) Suggest a concern about the disposal of solvents from drug manufacturing. [1]

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(d) Discuss **two** difficulties, apart from socio-economic factors, associated with finding a cure for AIDS. [2]

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(Option D continues on the following page)

(Option D continued)

26. Taxol is an anticancer drug.

(a) State the feature of Taxol that is a major challenge in its synthesis. Use section 37 of the data booklet. [1]

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(b) Describe how the challenge in (a) was resolved by pharmaceutical companies. [1]

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27. Nuclear medicine uses small amounts of radioisotopes to diagnose and treat some diseases.

(a) State **two** common side effects of radiotherapy. [1]

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(b) Explain why technetium-99m is the most common radioisotope used in nuclear medicine. [2]

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(Option D continues on the following page)

(Option D, question 27 continued)

(c) 25.0 µg of iodine-131, with a half-life of 8.00 days, was left to decay.

Calculate the mass of iodine-131, in µg, remaining after 32.0 days. Use section 1 of the data booklet. [2]

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End of Option D

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Answers written on this page
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